CLAIMS

1. A non-oriented electrical steel sheet comprising: on a mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: 5% or less (including 0%); and

Cu: 0.2% to 4%,

wherein the yield stress is not less than CYS (MPa) represented by the following formula 1:

note

$$CYS = 180 + 5{,}600[\%C] + 95[\%Si] + 50[\%Mn] + 37[\%Al] + 435[\%P] + 25[\%Ni] + 22d^{-1/2} \quad \cdots\cdots \text{(Formula 1)}$$

where d is an average grain diameter (mm) of crystal grains.

2. A non-oriented electrical steel sheet comprising: on a mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: 5% or less (including 0%); and

Cu: 0.2% to 4%,

wherein a volume ratio of Cu precipitates in crystal grain interior is in the range of from 0.2% to 2%, and

an average particle size of the Cu precipitates is in the range of from 1 to 20 nm.

3. A non-oriented electrical steel sheet comprising: on a mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: 5% or less (including 0%); and

Cu: 0.2% to 4%,

wherein the yield stress is not less than CYS (MPa) represented by the following formula 1,

a volume ratio of Cu precipitates in crystal grain interior is in the range of from 0.2% to 2%, and

an average particle size of the Cu precipitates is in the range of from 1 to 20 nm:

note

CYS =180+5,600[%C]+95[%Si]+50[%Mn]+37[%Al]+435[%P]+25[%Ni]+

$22d^{-1/2}$ ····· (Formula 1)

where d is an average grain diameter (mm) of the crystal grains.

4. A non-oriented electrical steel sheet comprising: on a mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: 5% or less (including 0%); and

Cu: 0.2% to 4%,

Wherein, after aging treatment is performed at 500°C for 10 hours, the yield stress of the steel sheet is not less than CYS (MPa) represented by the following formula 1:

note

CYS =180+5,600[%C]+95[%Si]+50[%Mn]+37[%Al]+435[%P]+25[%Ni]+ $22d^{-1/2}$ ····· (Formula 1)

where d is an average grain diameter (mm) of crystal grains.

5. The non-oriented electrical steel sheet according to one of Claims 1 to 4, further comprising at least one of Zr, V, Sb, Sn, Ge, B, Ca, a rare earth element, and Co as a

component,

wherein the content of each of Zr and V is 0.1% to 3%,

the content of each of Sb, Sn, and Ge is 0.002% to 0.5%,

the content of each of B, Ca, and the rare earth element is 0.001% to 0.01%, and

the content of Co is 0.2% to 5%.

6. A method for manufacturing a non-oriented electrical steel sheet, comprising the steps of:

performing hot rolling of a steel slab containing on a mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: less than 0.5% (including 0%); and

Cu: 0.2% to 4%,

then performing cold rolling or warm rolling to obtain a rolled steel sheet having a final sheet thickness,

then performing finish annealing in which heating is performed to a Cu solid solution temperature + 10°C or more, followed by cooling in which a cooling rate in a temperature range of from the Cu solid solution temperature to 400°C is 10°C/s or more; and

subsequently performing aging treatment at a temperature in the range of from 400 to 650°C.

7. A method for manufacturing a non-oriented electrical steel sheet, comprising the steps of:

performing hot rolling of a steel slab containing on a mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: less than 0.5% (including 0%); and

Cu: 0.2% to 4%,

then performing cold rolling or warm rolling to obtain a rolled steel sheet having a final sheet thickness,

then performing finish annealing in which heating is performed to Ts represented by the following formula 2 + 10°C or more, followed by cooling in which a cooling rate in a temperature range of from Ts to 400°C is 10°C/s or more; and

subsequently performing aging treatment at a temperature in the range of from 400 to 650°C:

note

$$Ts\ (°C)=3,351/(3.279-\log_{10}[\%C])-273 \quad \cdots\cdots \text{(Formula 2)}.$$

8. A method for manufacturing a non-oriented electrical steel sheet, comprising the steps of:

performing hot rolling of a steel slab containing on a mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: 0.5% to 5%; and

Cu: 0.2% to 4%,

then performing cold rolling or warm rolling to obtain a rolled steel sheet having a final sheet thickness,

then performing finish annealing in which heating is performed to a Cu solid solution temperature + 10°C or more, followed by cooling in which a cooling rate in a temperature range of from the Cu solid solution temperature to 400°C is 1°C/s or more; and

subsequently performing aging treatment at a temperature in the range of from 400 to 650°C.

9. A method for manufacturing a non-oriented electrical steel sheet, comprising the steps of:

performing hot rolling of a steel slab containing on a

mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: 0.5% to 5%; and

Cu: 0.2% to 4%,

then performing cold rolling or warm rolling to obtain a rolled steel sheet having a final sheet thickness,

then performing finish annealing in which heating is performed to Ts represented by the following formula 2 + 10°C or more, followed by cooling in which a cooling rate in a temperature range of from Ts to 400°C is 1°C/s or more; and

subsequently performing aging treatment at a temperature in the range of from 400 to 650°C:

note

$$Ts\ (°C)=3,351/(3.279-\log_{10}[\%C])-273 \quad \cdots\cdot \text{(Formula 2)}.$$

10. The method for manufacturing a non-oriented electrical steel sheet, according to one of Claims 6 to 9,

wherein the steel slab further contains at least one of Zr, V, Sb, Sn, Ge, B, Ca, a rare earth element, and Co,

the content of each of Zr and V is 0.1% to 3%,

the content of each of Sb, Sn, and Ge is 0.002% to 0.5%,

the content of each of B, Ca, and the rare earth element is 0.001% to 0.01%, and

the content of Co is 0.2% to 5%.

11. A method for manufacturing a non-oriented electrical steel sheet, comprising the steps of:

performing hot rolling of a steel slab containing on a mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: less than 0.5% (including 0%); and

Cu: 0.2% to 4%,

then performing cold rolling or warm rolling to obtain a rolled steel sheet having a final sheet thickness, and

then performing finish annealing in which heating is performed to a Cu solid solution temperature + 10°C or more, followed by cooling in which a cooling rate in a temperature range of from the Cu solid solution temperature to 400°C is 10°C/s or more.

12. A method for manufacturing a non-oriented electrical steel sheet, comprising the steps of:

performing hot rolling of a steel slab containing on a mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: less than 0.5% (including 0%); and

Cu: 0.2% to 4%,

Then performing cold rolling or warm rolling to obtain a rolled steel sheet having a final sheet thickness, and

then performing finish annealing in which heating is performed to Ts represented by the following formula 2 + 10°C or more, followed by cooling in which a cooling rate in a temperature range of from Ts to 400°C is 10°C/s or more:

note

$$Ts\ (°C)=3,351/(3.279-\log_{10}[\%C])-273 \quad \cdots\cdot \text{(Formula 2)}.$$

13. A method for manufacturing a non-oriented electrical steel sheet, comprising the steps of:

performing hot rolling of a steel slab containing on a mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: 0.5% to 5%; and

Cu: 0.2% to 4%,

then performing cold rolling or warm rolling to obtain a rolled steel sheet having a final sheet thickness, and

then performing finish annealing in which heating is performed to a Cu solid solution temperature + 10°C or more, followed by cooling in which a cooling rate in a temperature range of from the Cu solid solution temperature to 400°C is 1°C/s or more.

14. A method for manufacturing a non-oriented electrical steel sheet, comprising the steps of:

performing hot rolling of a steel slab containing on a mass percent basis,

C: 0.02% or less (including 0%);

Si: 4.5% or less;

Mn: 3% or less;

Al: 3% or less;

P: 0.5% or less (including 0%);

Ni: 0.5% to 5%; and

Cu: 0.2% to 4%,

then performing cold rolling or warm rolling to obtain a rolled steel sheet having a final sheet thickness, and

then performing finish annealing in which heating is performed to Ts represented by the following formula 2 + 10°C or more, followed by cooling in which a cooling rate in a temperature range of from Ts to 400°C is 1°C/s or more:

note

$$Ts\ (°C)=3,351/(3.279-\log_{10}[\%C])-273 \quad \cdots\cdot \text{(Formula 2)}.$$

15. The method for manufacturing a non-oriented electrical steel sheet, according to one of Claims 11 to 14,

wherein the steel slab further contains at least one of Zr, V, Sb, Sn, Ge, B, Ca, a rare earth element, and Co,

the content of each of Zr and V is 0.1% to 3%,

the content of each of Sb, Sn, and Ge is 0.002% to 0.5%,

the content of each of B, Ca, and the rare earth element is 0.001% to 0.01%, and

the content of Co is 0.2% to 5%.